IBECS Demonstration Network

Final Report

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Introduction

This report describes the demonstration network established at Lawrence Berkeley National Laboratory's Building 90 to test the IBECS (Integrated Building Environmental Communications System) being developed by LBNL. IBECS is a new networking system that provides effective control of lighting and other electrical systems in a building through the Internet. The first section provides background information on the demonstration project. We then outline the general goals and technical objectives of the project. The next section details the network design and installation and gives information on each component. We also describe the different software programs tested to operate the prototype network. Finally, we discuss the lessons learned from installing this demonstration network.

Background

The Integrated Building Environmental Communications System (IBECS) being developed by LBNL is a way to more effectively control lighting and other electrical systems in a building through the Internet, in order to increase energy efficiency, improve building performance and enhance occupant experience in the space. To demonstrate to potential industrial partners that an internet-based control and communications network for lighting systems has merit, LBNL is currently constructing and testing a fully-configured IBECS network onsite in the Building 90-3111 suite. This demonstration network is comprised of a sufficiently rich set of actuators and sensors as to make this a real test of how well the IBECS network concept allows communication between components to control lighting and envelope systems. The network employs a full range of IBECS-compatible technologies for lighting, automated blind systems, sensors and power measurement.

Objectives

The purpose of this demonstration network is to test the reliability of the IBECS communications network as it operates in a realistic, semi-uncontrolled office environment. The demonstration will provide a full range of efficiency and comfort control as well as enabling load management and demand response functions. Using this network, building occupants will be able to control their overhead lights and motorized blinds from their computers via the Internet. The IBECS demonstration network and systems testing will serve as an initial "proving ground" so that potential industrial partners may better evaluate the technology, its functionality and its appropriateness for solving the major problems facing the deployment of advanced control systems. Outside parties will also be able to observe the system performance in real-time using a secure web link.

The demonstration network serves as a platform to research the following technical issues. These include:

- Testing of bandwidth issues relative to multiple, heterogeneous IBECS devices operating in a semi-controllable, but realistic environment.
- Testing the usefulness of accessing, reading and adjusting devices on the IBECS demonstration network via local computer and remotely over the web.
- Explore different commercial and pre-commercial software options for controlling and communicating with IBECS devices.
- Explore technical issues associated with developing software to implement different building control algorithms
- Investigate problems associated with installing low-voltage control cabling
- Marketing the IBECS concept to disparate industry vendors and potential funders using a functional and exciting demonstration network that can be viewed remotely using a web cam and accessed and controlled remotely.

Design of the Demonstration Network

This section describes the design approach and key technical features of the IBECS demonstration network. As the successful implementation of an IBECS system requires both hardware and software components, the IBECS demonstration network incorporates a rich set of lighting and window devices and sensors, as well as key software programs that enable control of these devices. The devices and associated control software are detailed further below.

Physical Layout

The IBECS demonstration network encompasses seven cubicles at LBNL's Building 90-3111 suite. The cubicles are occupied by administrative assistants, research associates and students performing computer and paper tasks. As shown in Figure 1, the office suite is illuminated by eight pendent-mounted lighting fixtures. Each eight-foot light fixture shown actually consists of two 2-lamp 4-ft fixtures butted end on. The first and third fixtures are controlled by one wall switch and the second and fourth by another. The ganged wall switch is located as shown in Figure 1 [add this detail to the figure].
Note that the overhead lights are not the only source of illumination for the cubicles. There is significant daylight coming through the southwest facing window and the occupants working there sometimes choose to work without electric lights. Each cubicle has generally one overhead light (60 watts) that provide some or most of their lighting needs. The following diagram shows the physical layout of the demonstration network.

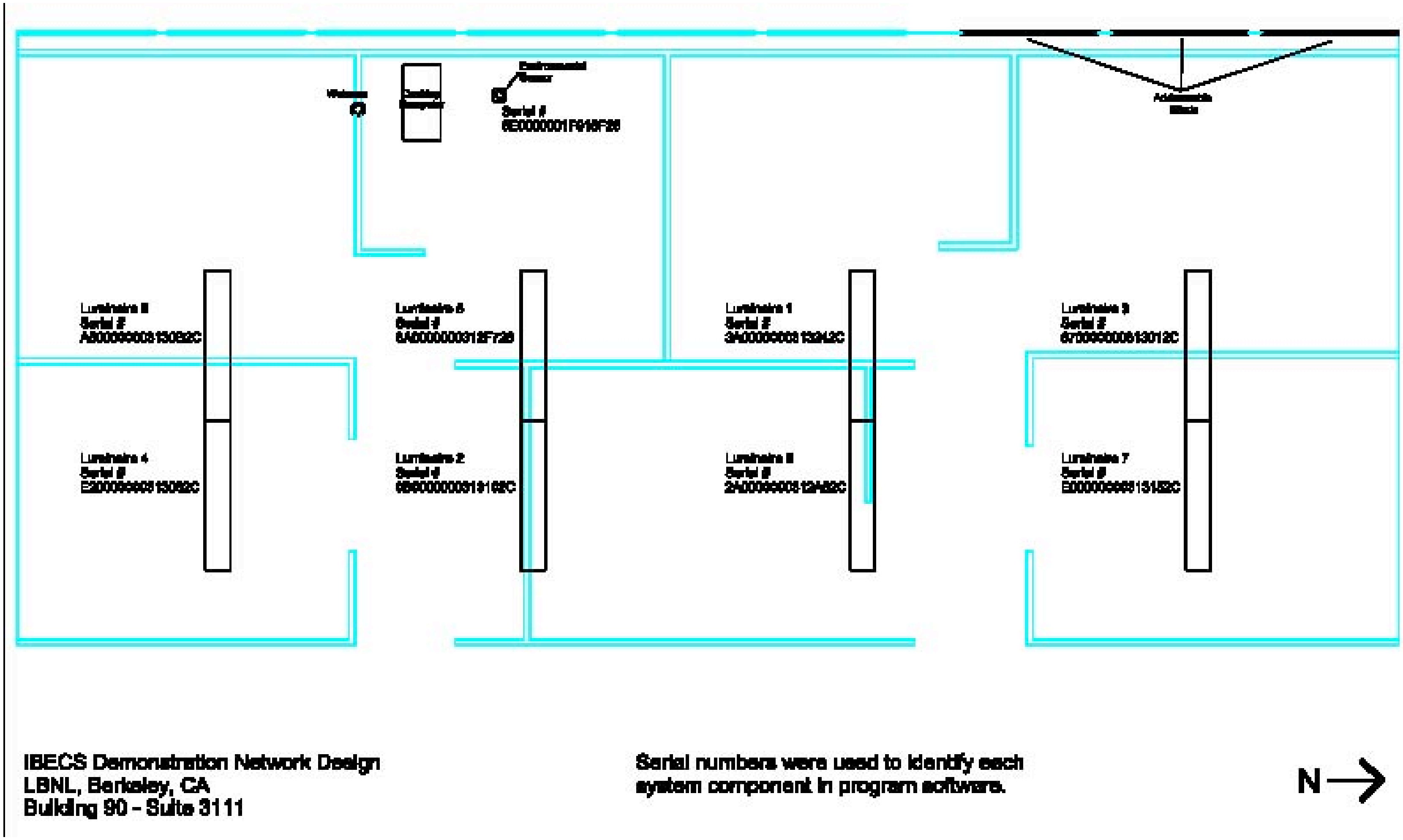


Figure 1. Physical layout of the IBECS demonstration network.

Network Components

As described previously, the IBECS demonstration network is comprised both of hardware and software components. We present the hardware components first:

- *Pendant-mounted luminaires*. The luminaires used in the demonstration network are suspended linear fluorescent direct/indirect fixtures (Litecontrol LC-90) that hold two 4' T-8 lamps per fixture (Figure 2). The existing ballasts were replaced with 0-10 VDC two-lamp dimmable electronic ballasts (Electronic Lighting Incorporated, SmartStart Series 700, D232.C277 Controlled Rapid Start Dimming Ballast). When set to full light output, each fixture consumes about 60 watts.

Figure 2. Picture of luminaires used in the IBECS demonstration.

- *Ballast Network Interface*. Each dimming ballast is equipped with one IBECS ballast interface (Figure 3) allowing each fixture to be individually dimmed from 5% to 100% light output. As described in [reference] these IBECS network interfaces also allow the connected lamps to be switched off from the IBECS network**.**

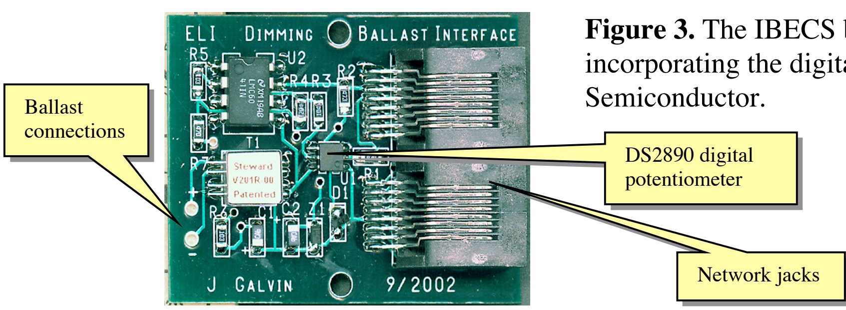


Figure 3. The IBECS ballast/network interface incorporating the digital potentiometer from Dallas Semiconductor.

- *Environmental sensor*. Initially, the task of environmental sensing was performed by a single device that monitored temperature, light levels, and occupancy of the space (see Figure 4). However, to improve performance, the environmental sensor was modified so that two separate devices monitor the environmental conditions of the space. One sensor now monitors illuminance at the workplane and temperature, while a second wall-mounted sensor monitors the occupancy of the space. In both situations, the sensors are used to monitor environmental conditions for only one office cubicle. However, environmental sensors to monitor the entire Building 90-3111 suite as a whole will be implemented in the future.

Figure 4. A picture of the first prototype of the IBECS environmental sensor. This device was replaced by two separate sensors: one measuring workplane illuminance and temperature, the second sensor measuring local occupancy.

- *Power metering*. In the near future, two IBECS current monitors will be installed in each of the two switch legs serving the eight controlled luminaries. Each current monitor will therefore measure the power flowing to connected all the lights on the switchleg. As described earlier, there are four lights (consuming a maximum of 240 watts) on each switchleg. The prototype IBECS current monitors are not perfect power measuring devices as they measure only current not real power. Real power is the dot product of current and voltage and requires measuring not only the current in the circuit but also the voltage and its phase. A CAT5 cable will be run between the switch box where the current meters will be installed and the IBECS server in the west cubicle. The outputs from the two meters will thus be integrated into the IBECS network to allow collection of data on the instantaneous current data being consumed (Figure 5).

Figure 5. The IBECS current monitor.

- *Motorized blinds*. Three operable motorized blinds were installed in the northern most cubicle to control the sun coming through the southwest facing window. In the High Performance Commercial Buildings program, control of the motorized blinds was accomplished through a purpose-built IBECS interface [reference]. The IBECS interface enables one to control the tilt, raise and lower functions of motorized Venetian blinds via a One-Wire Dallas Semiconductor network from a virtual user LabView control panel installed on a PC. Next year, we will add software that will allow the blinds to be directly operated from IBECS without requiring the use of LabView.

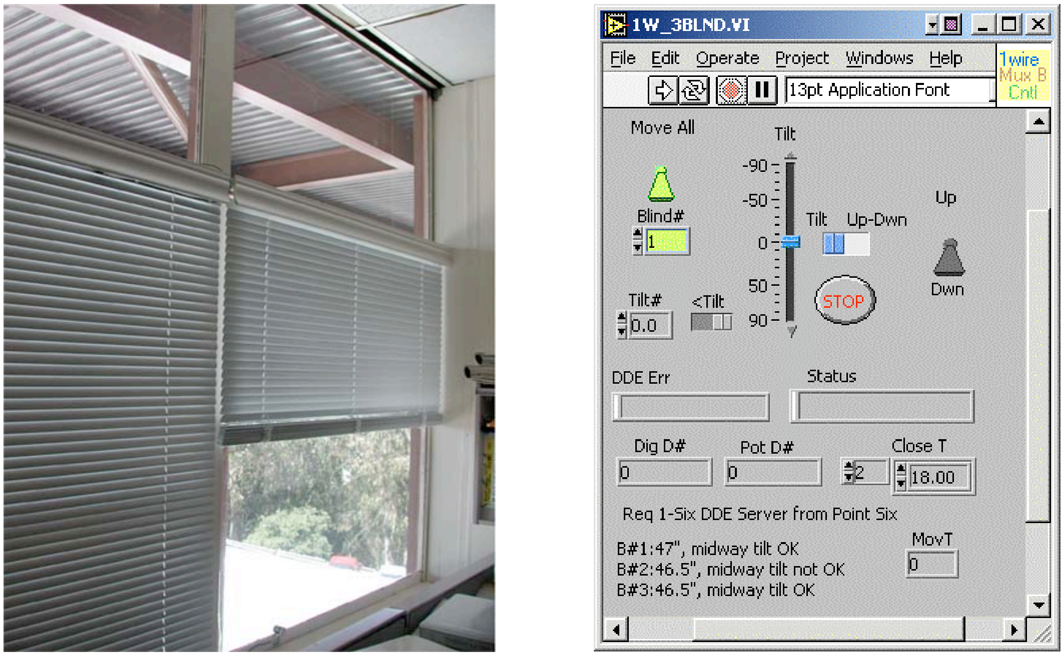


Figure 6. Left: Photograph of the installed Venetian blind system at LBNL. Right: Screen capture of the LabView "virtual instrument" panel used to control the operation of the IBECS-controlled Venetian blinds.

- *Webcam*. While not critical to the proper functioning of the demonstration network, a webcam is a useful addition to the network in that the webcam can both monitor the operation of network and help to spread the word on the benefits of improved network control to potential early adopters and manufacturers. The web cam is connected to the IBECS server in the same fashion as a typical web cam; it is directly connected to the IBECS server through the USB port on the PC. Using software running on the IBECS server, static images can be taken on a time-lapse or a live streaming video of the space can be viewed. Using streaming video, we could demonstrate the functioning of the network remotely without having to be physically present at LBNL to view the network capabilities. This capability will be useful to help persuade manufacturers of the power of the IBECS concept. Sample images taken from the IBECS demonstration network web cam can be seen in Figure 8.

Figure 7. Sample images from the IBECS web cam. Notice that each fixture can be individually switched on and off as well as dimmed over the full range.

- *IBECS Server*. The IBECS server consists of an Internet-connected PC running software needed to control and monitor the performance of the system including iButton-TMEX, Lab View, and IBECS software currently under development. A ***port adaptor*** (type DS 9097) is connected to the serial port of the IBECS Server to allow the PC to communicate with the IBECS network. The connections of the port adaptor to the PC are shown in the photos below (Figure 8).

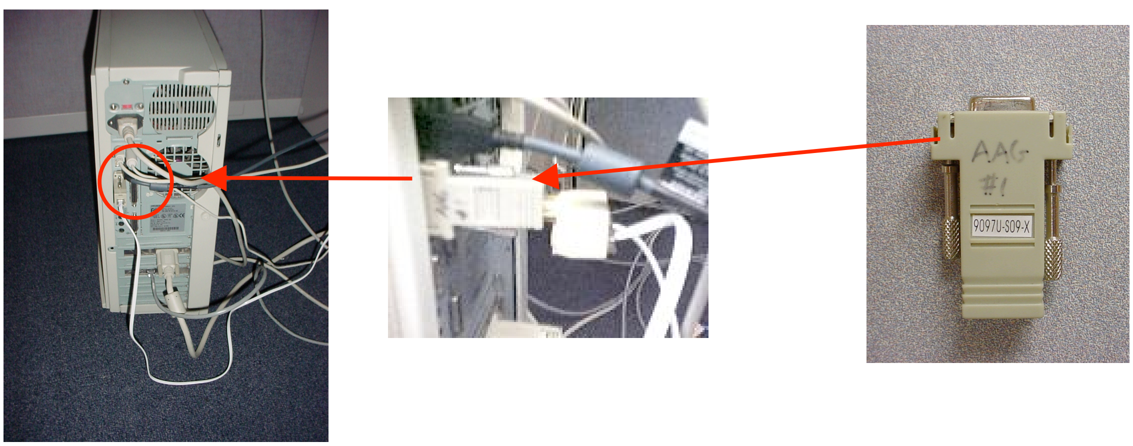


Figure 8. The port adaptor (far right) plugs into the serial port on the back of the IBECS server as shown in the far left and center photographs.

- *CAT5 cabling*. The network cabling used to connect all the components is simple CAT5 cable terminated with conventional RJ-45 connectors. All network cabling used to connect all devices emanates from the network connection junction box (figure 9). The network connection junction box acts as a hub for the network, consolidating all devices into a single 1-wire system that plugs into the port adaptor on the IBECS Server.

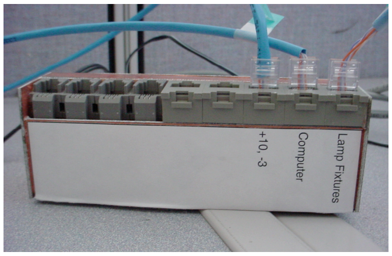


Figure 9. The network connection junction box is the hub for all the IBECS network wiring. The 1-wire commands from the PC-connected port adaptor go to the plug marked “computer.” +10 and –3 VDC is pulled from a specially built power supply and connected to port marked “+10, -3. The four wires to all the fixtures emanates from the plug marked “Lamp Fixtures”

- *Software* Using available public domain software as a starting off point, we designed and produced Java-based software that can control and communicate with the devices on the IBECS network and receive inputs from users through their networked PCs. There were three software programs used to operate the IBECS network. These programs are detailed individually in the Software section below.

Network Wiring

The IBECS Demonstration Network Design drawing (see appendix) documents the physical layout and connections between devices that operated in Building 90 - Suite 3111. As seen in the diagram, four of the luminaires in the design were connected to one switch, while the remaining four were controlled by the second switch. The male end of the ballast network interface connected to the female RJ-11 jack on each electronic ballast (Connection 1). The ballast network interfaces were equipped with two female RJ-45 jacks to provide the ability to daisy-chain them together (Connection 2). Examples of both RJ-11 and RJ-45 jacks and plugs can be seen in Figure A. The luminaires were connected into the IBECS system through a network connection junction box. This network connection junction box used all RJ-45 jacks and received feed from the luminaires, a current monitor and a power source to provide switching capability to the luminaires (Connection 3). It was then connected directly to the IBECS Server through a DS 9097 port adaptor. The port adaptor had a female y-connector RJ-11 jack attached in order to allow the environmental sensor to also be connected to the network (Connection 5). All the connections points and wiring specifics are detailed in Figure B.

Installation

Due to the need to replace all the existing ballasts with dimming ballasts, licensed electricians were needed to install the ballasts, network interfaces and low-voltage cabling throughout the IBECS demonstration network into Building 90 – Suite 3111. The installers replaced the original ballasts in each fixture with a dimmable electronic ballast. They then attached an IBECS network ballast interface to the ballast in each fixture (see Figure 10), and daisy-chained the different interfaces together with CAT5 cabling.

Figure 10. Installer fits diffuser into fixture that has just been retrofitted with a dimming ballast and an IBECS ballast network card (green card hanging from fixture)

Software Programs

Software is needed both to control the overhead lighting and envelope system according to automatic control strategies (daylighting and occupancy sensing, for example) as well as control from the occupants over the network. This software is still in the developmental stage, but one of our tasks was to test several different available packages so that we could begin to select the overall software development platform for IBECS. To date, there have been three software programs tested for operating the IBECS demonstration network: 1) iButton-TMEX, 2) Advantech GenieDAQ, and 3) a Java IBECS program. These programs are detailed individually below.

iButton-TMEX software

The iButton-TMEX software is developed and distributed free of charge by Dallas Semiconductor/MAXIM (see http://www.ibutton.com/software/tmex/index.html). This software was designed to allow developers of 1-wire hardware and software to inspect, read and control Dallas Semiconductor's 1-Wire family of microchips. While it performs these tasks well, TMEX was not designed to be a general control program and the user interface it provides for each component is opaque and difficult for the naïve user to understand.

When first opening the TMEX program, the software searches for all 1-wire devices on the connected network and creates a list of all the serial numbers that it finds. Each device has a globally-unique serial number that is published on the left-hand side of the main window. To change the output of any of the lights, the user double-clicks on the listed devices serial number to open a second window that is context sensitive to the chosen device type. Figure 11 shows the control window that TMEX throws up when controlling a digital potentiometer (the heart of the IBECS network ballast interface). As shown in Figure 11, this slider is labeled "Current Wiper Position." The user can choose either to move the slider or input a value directly into the box labeled "Set Wiper Position." Each light's output ranges from off to full and is measured on a scale from 0 to 255 (0 being off, 255 being full light output). The iButton-TMEX software also allows the user to view the status of the environmental sensors on the network by clicking on their unique serial numbers.

An obvious disadvantage of this software is that the labels on the user interface are not directly related to lighting fixtures and are thus not easily understandable to the average user. The numbering system for both the lights and the environmental sensors is arbitrary, which is why more personalized Java-based software is currently being developed by LBNL.

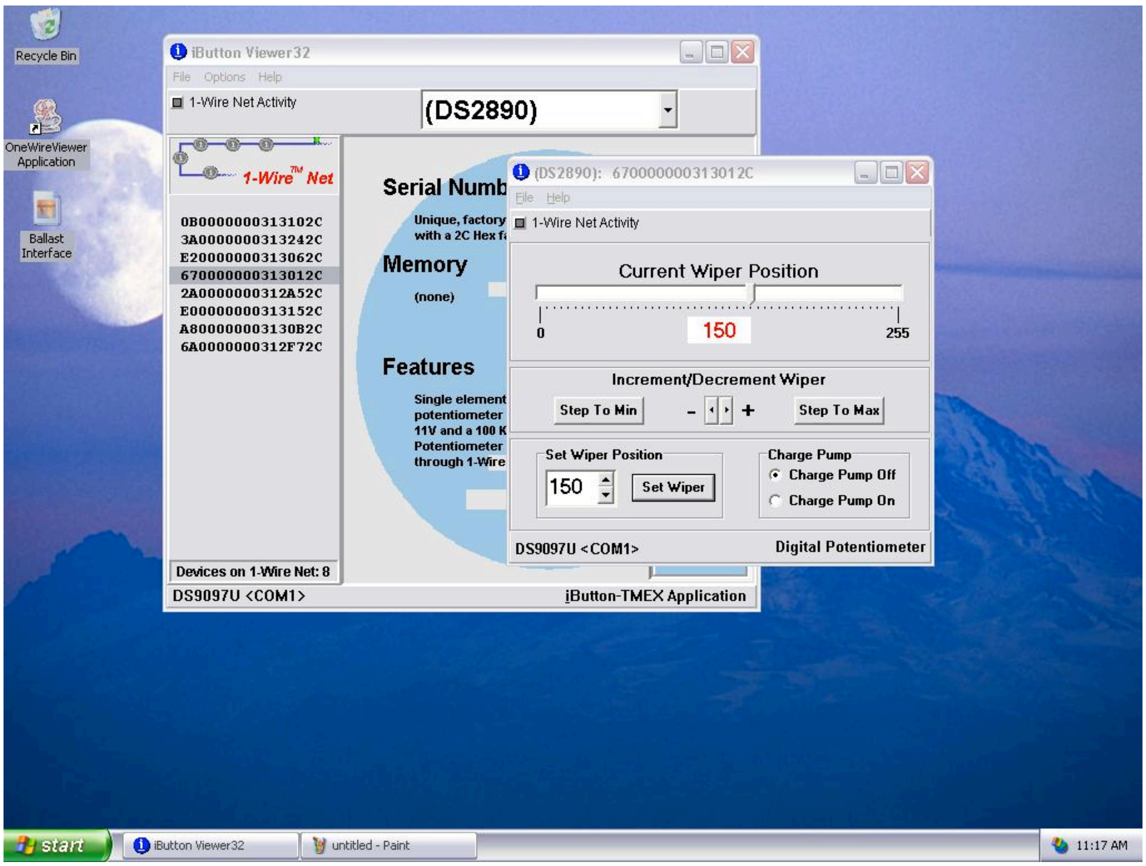


Figure 9. Screen capture of the iButton-TMEX user interface. The window in the background lists the serial numbers of all found devices in the left hand column of the window. The foremost window "pops-up" when the user double-clicks on a particular device number. Note that the foremost window allows the user to increment of decrement the wiper position which translates into raising or dimming the light level from the selected fixture. In addition, the user can also type a number between 0 and 255 into the "Set Wiper Position" edit field and then click "Set Wiper". The light will immediately go to that light level.

Java-based IBECS software

The second program used to operate the IBECS demonstration network was an early version of the Java-based software being developed at LBNL. The user clicks an executable file called "Run" to open the program. An MS-DOS screen appears and automatically searches for and locates all the IBECS devices on the network (Figure 11). After that task is finished, another small window opens with a separate tab created for each light on the network. To change the light's output, the user moved the slider up or down, somewhere between the same 0 to 255 range of values as in the iButton-TMEX program.

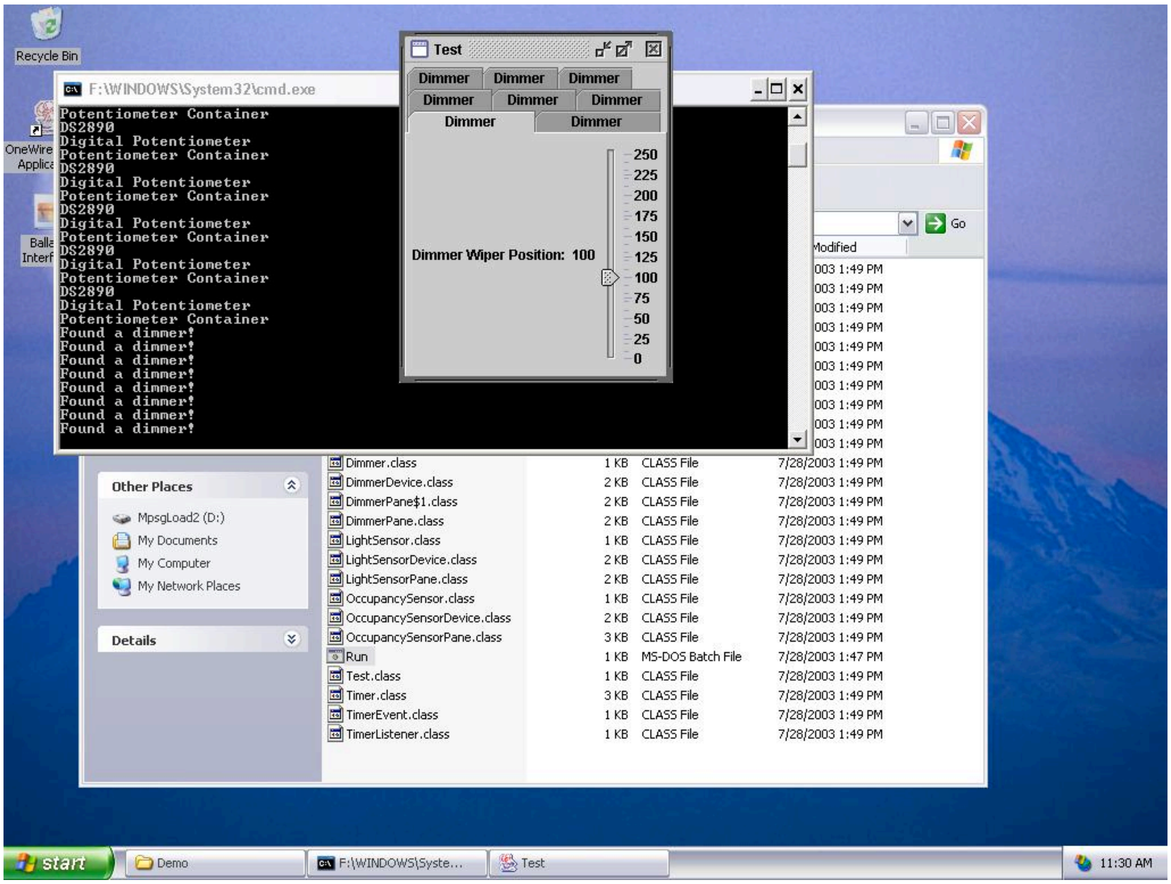


Figure 11. Screen capture of the Java-based IBECS user interface.

This software currently has the same labeling problems as the iButton-TMEX software, however it has the ability to be altered and catered to the characteristics of the network. Therefore, the software has much more potential to suit the needs of an IBECS network. Another benefit that this software has is that it can be implemented and operated entirely over the internet through the use of Java applets.

Advantech GeniDAQ software

The third program that was used to operate the IBECS demonstration network was a commercially developed program produced by the company Advantech. GeniDAQ is a data-acquisition program that was initially employed on the IBECS demonstration network due to its ease of use for designing user-friendly control panels. The design of the program makes it easy to create user interfaces and operate any DDE device.

Initially this program was used to operate a smaller IBECS network controlled from a laptop computer. This mock-up network consisted of a task light that could be "dimmed" with multiple switching levels, a true dimming fluorescent strip light, and an occupancy sensor. The true dimming strip light was referred to as "overhead lights" in the user interface in order to help distinguish the two fixtures from each other. A key goal was to create a user interface that was simple and easy to understand. This smaller IBECS demonstration network was used to demonstrate to visiting professionals some of the possibilities and options that existed in IBECS. A sample image of the user interface can be seen in Figure 10.

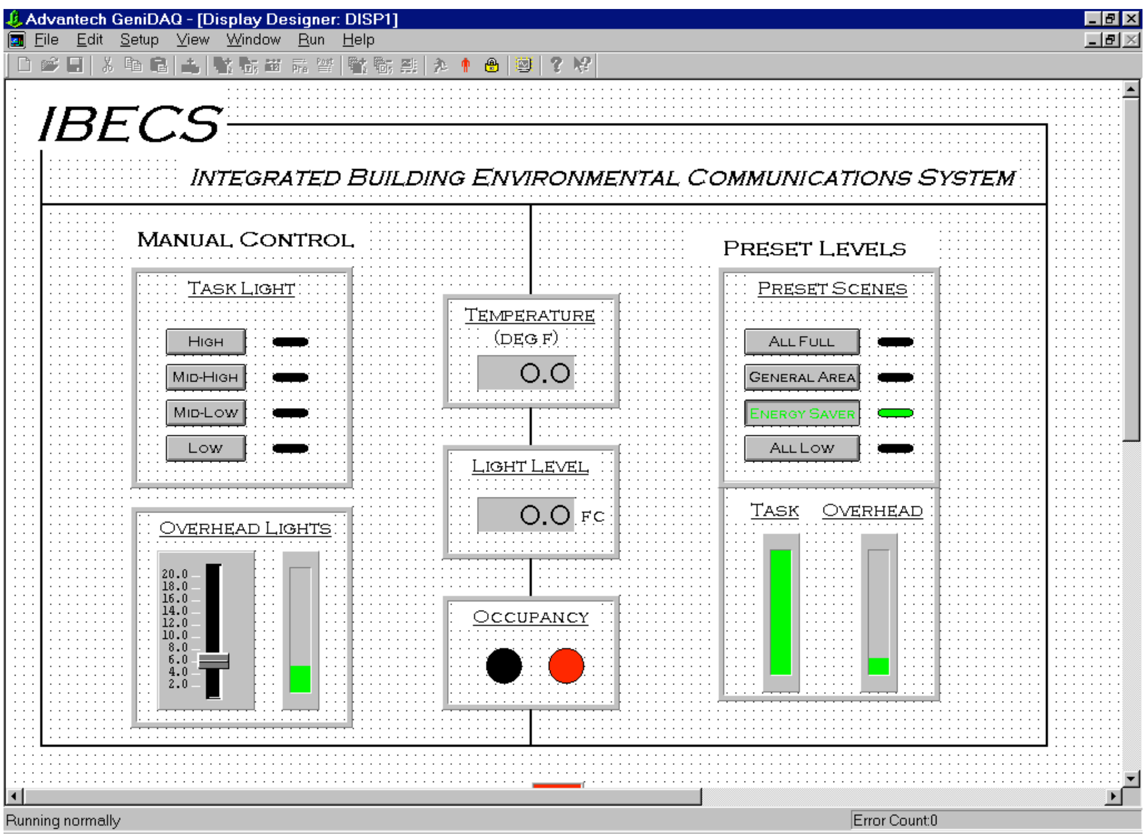


Figure 10. Screen capture of the IBECS user interface.

This interface replicates the form and function of conventional lighting control equipment and is therefore more intuitive to the typical lighting user.

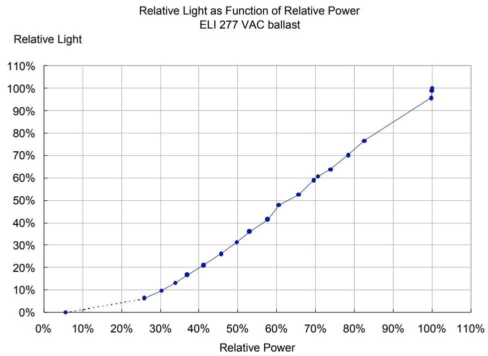
The left hand side of the screen is devoted to manual control of the equipment. The level of the task light can be changed by clicking the mouse over the desired light level button. The true dimming overhead light can be controlled by moving the slider up and down. The right side of the screen is dedicated to preset light scenes. Preset lighting scenes are commonly used in the lighting and theatrical design and are easily understood by designers and specifiers. These preset scenes combine the levels of the two fixtures used on the smaller IBECS demonstration network to achieve the desired light level. The four different scene names are All Full, General Area, Energy Saver and All Low. *All Full* puts both fixtures to full output. *General Area* consists of the overhead lights to be on full while the task light is on low. *Energy Saver* is the exact opposite, with the task light on full output and the overhead lights on low. Finally, *All Low* has both fixtures operating on low. The two meters below the preset scene buttons indicate the levels of each of the fixtures for the scene they are on. In the sample image, the Energy Saver scene is selected, so the task light is full and the overhead lights are on low. The three boxes in the middle of the sample image are for environmental sensors. The temperature and light level sensors were never fully implemented into the smaller IBECS demonstration network; however, the occupancy sensor was successfully operated in conjunction with the light fixtures.

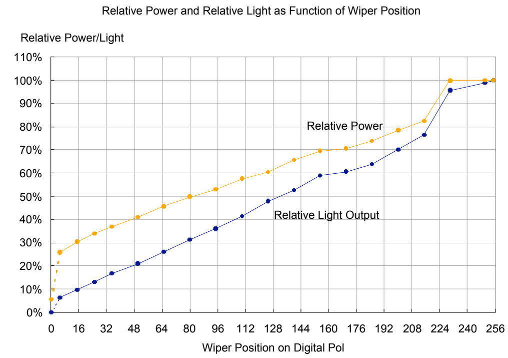
Although Genie DAQ has a number of nice features (especially the ability to prototype up different user interfaces quickly), the software appears to be on a deadend path. Our Version 4.0 would not work on a PC running the XP operating system, which is the de facto standard for the Berkeley Lab. Numerous attempts on our part to resolve this with Adventech engineers and customer support lead us to conclude that this program will not be supported for machine running Windows XP.

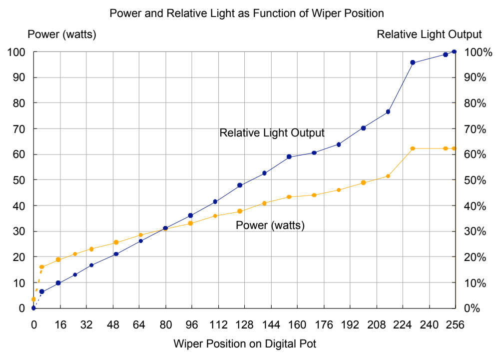
Discussion

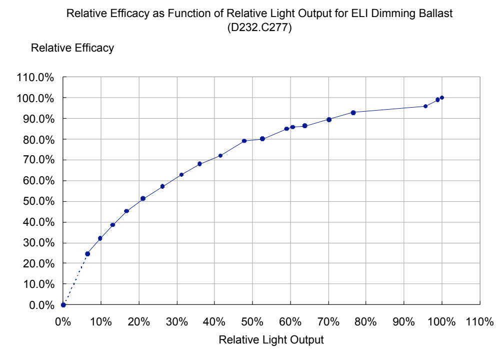
We measured the operation of representative fixtures in the network and produced plots showing the performance of the dimming ballasts controlled using the IBECS ballast network interfaces.

As shown in the graphs below, the interface can dim the ballast over its entire range (by varying the wiper position on the DS2890 digital pot). The ballast dims to a minimum dim level of 6% light output at which point the ballast consumes 16 watts (26% of maximum power). The minimum dim level corresponds to a wiper position of 5 (out of a possible 256 steps). When the interface is commanded to wiper position 0, the interface outputs about -2.2 VDC onto the ballast low-voltage leads causing the ballast to entirely extinguish the lamps. Although the lamps are visibly off, the ballast continues to consume about 3.5 watts (5.6% of full power). This small power draw, which is necessary to keep the ballast control circuit hot, can be considered the “standby losses” for this dimming ballast.









A key advantage to the improved interface is the ability to switch off lamps without having to insert a controllable switch on the ballast hot leg. Our solution offers full dimming range as well as lamp switching capabilities without the added expense of a switch.

Lessons Learned

In our demonstration network, we used a low-voltage cabling scheme that was tailored to control the specific network ballast interfaces in the ceiling lighting system. This low-voltage cable contained 4 conductors and we used all four conductors: two for the 1-wire signal and return and two for the +10 VDC and –3 VDC needed to properly operate the ballast interfaces. The ballasts and ballast network interfaces required +10 VDC for the operational amplifiers on the board (not that unusual). The –3 VDC was necessary to allow the interface to switch off the lamps (by providing –3 VDC to the low-voltage ballast leads, these particular ballasts can switch off the connected lamps). Although it is impressive to show full dimming AND off control all from the low-voltage, our solution became overly specialized and difficult to implement. We found that not all dimming ballasts even allow their lamps to be switched off in this manner and even those companies that do offer this feature, often implement it differently. Bottom line is that it is awkward and ungainly to use up two additional wires (in a four wire cable) for instrumentation voltage. With four wires, it is more likely that the installers to make errors (since four wires must be connected rather than two) and so four-wire cabling is less likely to be adopted by the industry. For example, the DALI protocol requires only two wires in the cable and this effectively “raises the bar” on other digital network developers to use just two wires also. In the future, IBECS cabling will require only two wires.

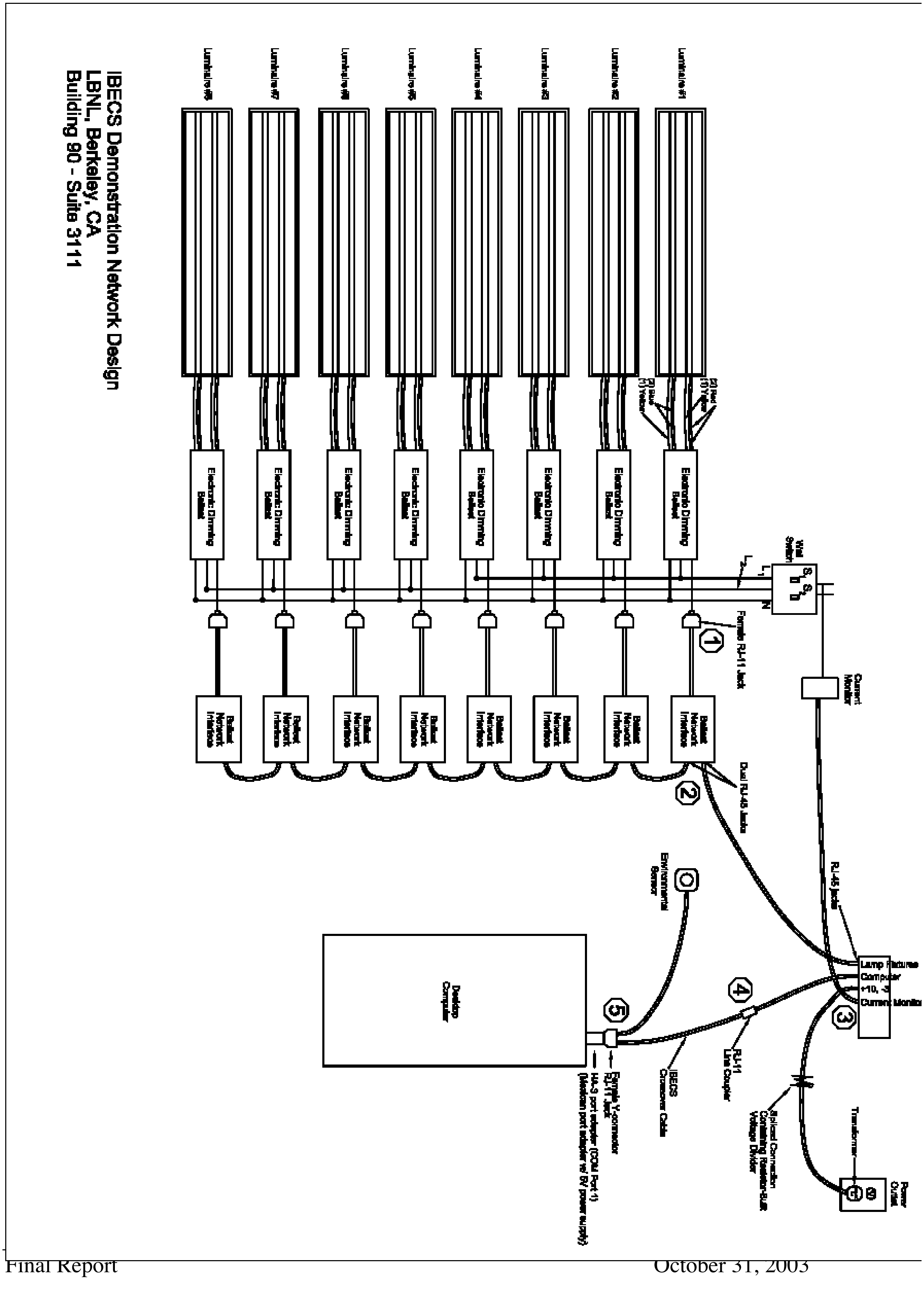
A second lesson we learned is that it is not good to combine switching and dimming on one interface. Although we demonstrated successful operation of just such a board, in retrospect the disadvantages outweigh the advantages. When switching off the lamps from the low-voltage, the ballast still draws 5-6% power even though the lamps produce no light. This raises the spectre of energy vampires (components that use power even when not providing useful function). We believe that it is better to confine switching to switching of the switchleg going to the ballasts. When such a switch is in the OFF position, the lighting system draws no power. This addressable switch could be conveniently located in the electrical junction box or even the switchbox serving the controlled area.

In terms of software development, we are not satisfied with any of the programs that we tested or developed to operate the IBECS demonstration network. TMEX is only good for peeking and poking at Dallas devices, not for an industrial strength control program. The Advantech GenieDAQ software suite looked promising for rapid prototyping of user interfaces, but it seems to be on a dead end path as far as vendor support for Windows XP is concerned. The Java control programs that we developed are promising, but they are time-consuming to develop and de-bug.

There are two new approaches to software development that we would like to explore. One involves the use of the Mediator (by EnvEnergy) which promises to be a multi-prototcol environment that would be capable of integrating the functionality of IBECS, BACnet and even DALI along the lines of the framework set down by Rubinstein, Treado and Pettler in “Standardization of Lighting Control Devices: A Role for IEEE P1451”.

A second simpler approach involves the testing of a control program by Roso Controls called DDE Viewer. This inexpensive program (under $40) just came on the market in August 2003 and promises to be a good program for controlling and reading 1-wire devices. The program has a much better interface than TMEX and seems to support all the 1-wire devices that we use in IBECS.

Acknowledgements


IBECS Demonstration Network Design
LBNL, Berkeley, CA
Building 90 - Suite 3111
Electronic Dimming Ballast
Ballast Network Interface
Wall Switch
Female RJ-11 Jack
Current Monitor
Dual RJ-45 Jacks
RJ-45 Jacks
Environmental Sensor
Desktop Computer
Lamp Fixtures
Computer
Current Monitor
RJ-11 Line Coupler
IBECS Crossover Cable
Female Y-connector RJ-11 Jack
Transformer
Power Outlet
1
2
3
4
5

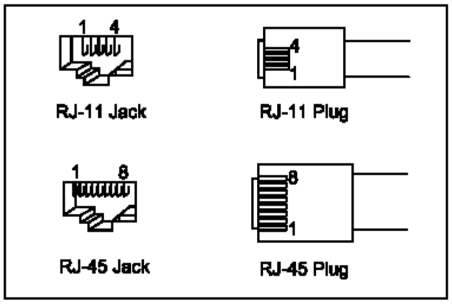


Figure A

Wiring Legend

1 RJ-11

Wire #	Detail
1	Empty
2	Signal
3	Ground
4	Empty

2 RJ-45

Wire #	Detail
1	Empty
2	Empty
3	+10 V
4	Signal
5	Ground
6	-3 V
7	Empty
8	Empty

3 RJ-45

Wire #	Detail
1	Empty
2	Empty
3	+10 V
4	Signal
5	Ground
6	-3 V
7	Empty
8	Empty

4 RJ-11

Wire #	Detail
1	Empty
2	Signal
3	Ground
4	Empty

5 RJ-11

Wire #	Detail
1	Empty
2	Signal
3	Ground
4	Empty

*Connection numbers referenced from IBECS Preliminary Design drawing

Figure B